Ring cathode electron beam projection lithography

W.K. Ang, A. Khursheed*, C. Peeris, V. Ng, K.L. Zhong
Department of Electrical and Computer Engineering, National University of Singapore, Singapore 117576
**eleka@nus.edu.sg*

Recently, a new cold field emitter has been fabricated, which consists of a graphene-coated ring-shaped cathode[1]. Preliminary experimental results show that it can produce high emission currents at relatively low applied electric field strengths in HV conditions (as opposed to the usual required UHV conditions). This ring-cathode emitter has the potential to serve as a promising high brightness electron source suitable for electron lithography. In this paper, the novelty of writing a ring-shaped pattern directly from the cathode, as opposed to using a point source in combination with a patterned aperture will be examined. To this end, numerical simulations are carried out using a simple test column consisting of an electron source, an aperture and a magnetic objective lens as shown in Figure 1. A high resolution ring-shaped pattern is obtained from direct ray tracing for the ring-cathode column with a conventional hole-aperture. Aberration analysis reveals third-order geometric aberrations in the in-plane direction, which is an order of magnitude better than that predicted for a point source emitter with an annular aperture, which has second-order geometric aberrations. A ring width resolution of 1.4 nm is predicted for a 5 kV-beam ring-cathode column where the ring image radius is 0.4 µm, the final semi-angle is 2 mrad and the working distance is 5 mm. In comparison, the corresponding point source column is predicted to have a resolution of 14.3 nm, an order of magnitude worse. Figure 2 shows simulated ring widths versus final semi-angular spread for both columns. These simulation were carried out through the use of Lorentz-2EM[2], a boundary element software for direct ray tracing of electron trajectory paths. The kinds of simulation results point towards the possible use of ring cathode emitters for ring pattern generation in electron beam lithography where high spatial resolution is combined with high throughput.

Different cathode layouts will be microfabricated and experimentally tested in a homemade electron-beam projection column. The emission patterns of structures such as concentric ring cathodes will be analysed and compared to simulation predictions.

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[1] X. Shao, A. Srinivasan, Y. Zhao and A. Khursheed, Carbon 110, 378-383 (2016).
[2] Lorentz-2EM (Integrated Engineering Software Inc., Winnipeg, 2016).
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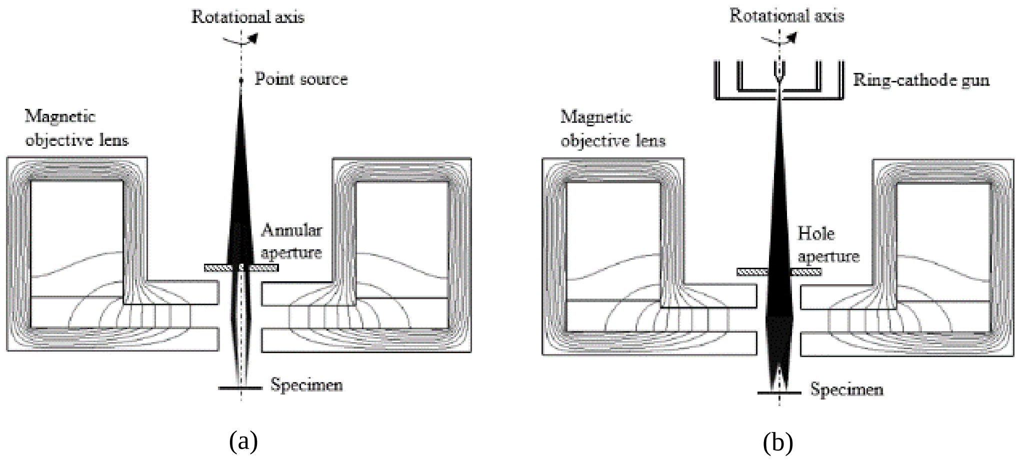

Figure 1: Schematic diagrams for ring pattern writing. (a) Conventional point electron source with an annular aperture. (b) Ring-shaped electron source with a conventional hole-aperture. The focused beam in both cases will produce a ring-shaped pattern on the specimen surface.

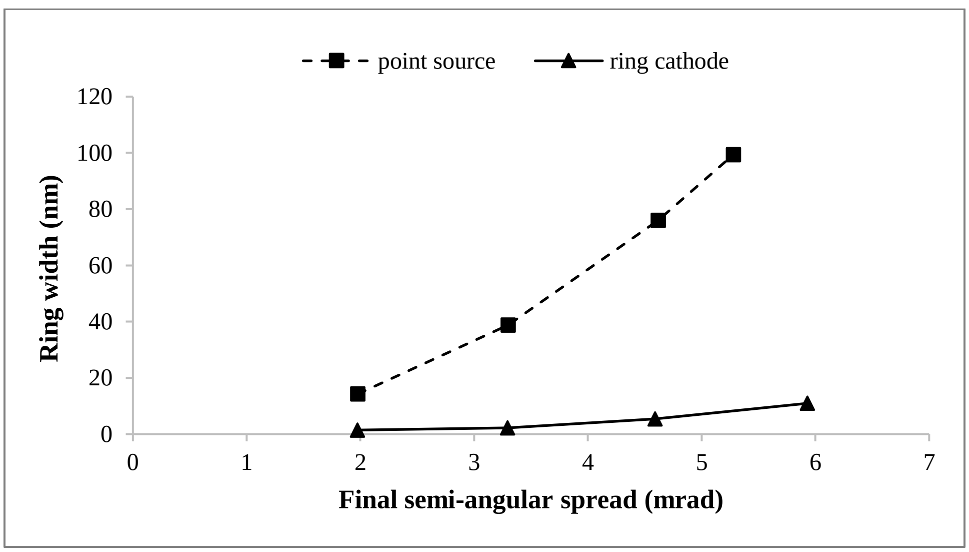

Figure 2: Focused ring width as a function of the final semi-angular spread. The focused rings have comparable radii in both models: 460 nm for the point source and 422 nm for the ring cathode case. The much improved resolution obtained for the ring cathode case is due to the intrinsic third-order geometric aberrations of the ring-cathode column compared to the second-order geometric aberrations of the point source column with an annular aperture.